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# Thermal characterization of materials based on clay and granular: cork or expanded perlite.

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**Abstract**

For the purpose of resisting to the hard climatic condition and so as to improve the insulation of building material in the Ben Smim Ifrane region, we proceeded in this work to develop local materials, clay is a building material very used in walls or floor in this region, The goal consists to improve the thermal properties of clay bounded with granular cork and compared with the thermal properties of the same clay with expanded perlite.
The first step in this study is the chemical characterization of the clay by means of X-ray diffraction. The results show that the clay sample is mainly made up of Illite/ muscovite which is a non-swelling clay. The second step is the thermal characterization of clay bounded with cork or expanded perlite by using the methods: Hot plate and Flash. Then a comparison of their densities and thermal properties was done in both cases: air dried and heated.
Finally a Comparison of the energy saving was done to determine the best materials in order to manufacture full bricks done from clay-cork or clay-expanded.


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*Keywords:* Illite Clay –expanded perlite, Illite Clay-cork, Hot plate method, Flash method Thermal conductivity, Thermal block air dried Thermal block heated.

## 1. Introduction

Clay is an environmentally material used in construction especially in mountainous regions and Saharan where the population is often poor in all countries of the world, particularly in Africa. The objective of this work is to improve the thermal properties and the lightness of the clay by combining it with granular cork or expanded perlite in order to encourage the using of our materials in construction building within those areas, that's why authors try in


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this work to improve the insulation of construction materials by combining clay with granular cork or expanded perlite.
A literature study on insulation building materials cork and expanded perlite was investigated, so as to realize this work such as the work of Jelle and al.[1] concerning the state of the art on innovative thermal insulation materials and solution. Another work for cherki and al. concerning Granular Cork Content Dependence of Thermal Diffusivity, Thermal Conductivity and Heat Capacity of the Composite Material/Granular Cork Bound with Plaster[2].Another for Gandage and al. determining the thermal properties of a concrete bounded with perlite [3].Another for Abrouki, Y and al. concerning the characteristics of perlite in Nador city : Investigation of the basis for catalytic activity of expanded Perlite in Knoevnagel condensation[4]. Also a lot of works have been done on clay such as the work of Mounir S. and al. concerning the study of the effect of cork on the thermal properties of the composite clay-cork[5], Laaroussi and al. [6]which object is the Measurement of thermal properties of brick materials based on clay mixtures Another research[7] for Mucahit Sutcua, and al. treating the thermal performance of clay with the waste of the paper “Thermal performance optimization of hollow clay bricks made up of paper waste”.In the present work, we aim to study the choice of the best granular (cork or expanded perlite) so as to combine it with clay .The study explain the rule of granular on the improvement of the thermal properties. The thermal characterization of the materials is conducted by the use of the recent asymmetrical Hot Plate [8–10] and Flash methods[10–12]. The effect of the variation of the volume fraction of granular cork or expanded perlite and the effect of the calcination on the thermal properties of the brick is also studied. Also a comparison of the energy saving and the energy dissipated (energy of calcination).Moreover the ease of manufacturing process was studied.

Perlite is a general term for a glassy, volcanic and rhyolitic rock which will expand when quickly heated to above 870°C. It expands up to 20 times its original volume. This known as expanded perlite. Because of its low density perlite is used in many fields, such as ceiling tile, pipe insulation, gypsum wallboard and cryogenic insulation[13].

cork is natural, ecological and renewable product with thermal and acoustic properties very interesting due to their micro structure and porosity. It is coming from Moroccan Maamora's forest. As we will see later in this work, the clay extracted from Ben smim is mainly made up from Illite.

Illite Clay is a mineral similar to muscovite with an organization of layers (2: 1): (Te-Oc-Te); with a basal spacing of 10 Å, but is typically deficient in alkalies, with less Alumium substitution for Silicium. Thus, the general formula for the Illite is:

$KxAl_4$ ($Si_8$-x, Alx) O20 (OH) $_4$, usually with $1 < x < 1.5$, but always with $x < 2$. Thus, Illite is basically made up of one octahedral sheet and two tetrahedral sheets. Potassium bonding, that balances the charge deficiency caused by the replacement of Si4+ in the tetrahedral sheet by $Al_3$+, makes of Illite non-swelling and non-shrinking clay. It is to be noted that this clay is frequently used in engineering applications.

**Nomenclature**

| | |
|---|---|
| a | thermal diffusivity ($m^2.s^{-1}$) |
| *E* | thermal effusivity ($J.m^{-2}.K^{-1}.s^{-1/2}$) |
| C | clay |
| C+co | composite clay-cork |
| C+ep | composite clay-expanded perlite |
| $y_c$ | Volume fraction Cork |
| $y_{ep}$ | Volume fraction Expanded perlite |
| *Ø* | heat flow (W) |

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## 2. Description of the used materials

### *2.1. Expanded perlite*

Expanded perlite object of work was taken from Jbel Tidiennit which was already treated by Abrouki Y. and al. [4] Perlite is a glassy volcanic rock commonly light gray with a rheolitic composition and 2-5% of combined water. Commercially, the term perlite includes any volcanic glass that will expand or pop when heated quickly. It can be noted that EP is natural alumino-silicate rich in SiO and $Al_2O_3$.The density of the used Moroccan expanded perlite is 114 Kg.m-3; the thermal conductivity is 0.062 $W.m^{-1}. K^{-1}$.

Fig.1.View of Granular expanded perlite

### *2.2. Clay*

The clay sample extracted from Bensmim area close to Ifrane was characterized through X-ray diffraction. The results are represented in figure 2.

The results presented above show that the X-Ray diffraction of the powdered soil sample presents various peaks occurring at different positions. A predominance of quartz in the soil, SiO2 (d=3.34Å). The Clayed part is composed of Muscovite/Illite (d =10.00 Å).

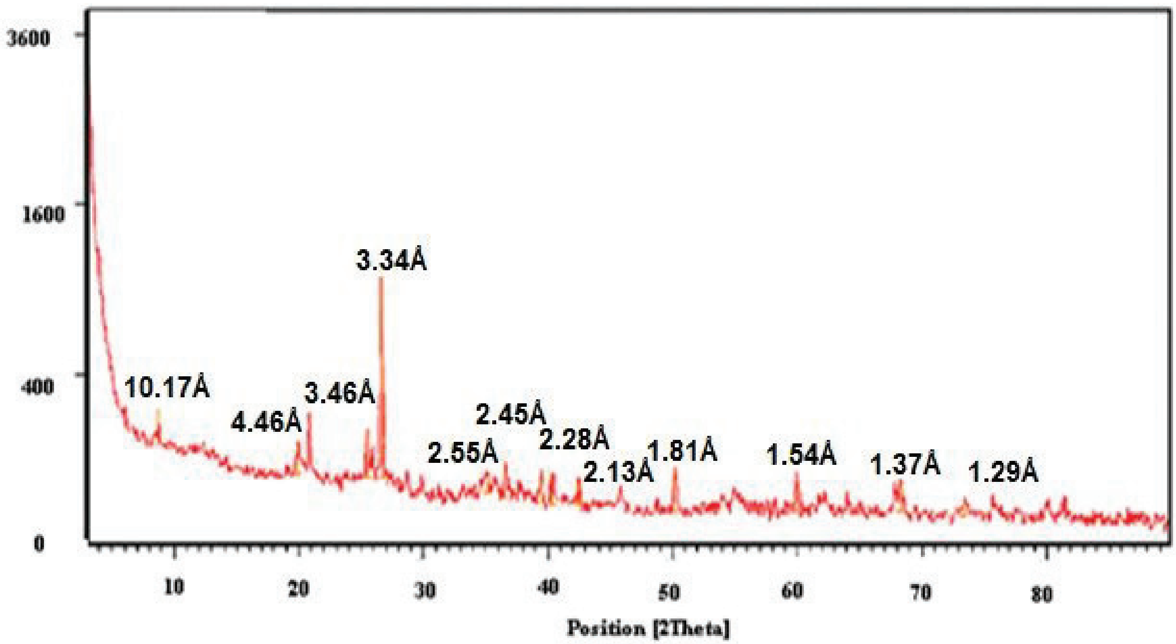


Fig.2. X-Ray diffractometer spectrum of the clay sample extracted from Ifrane Region

More XRD analysis was conducted through oriented planes to study more the clay part of the sample. The results are represented in the figure 3.

The figure 3 confirms the presence of the non swelling clay Illite/muscovite clay reflection d=10.00 A°. present at the angle 2θ equal 8° at the interatomic spacing. No change in the present pics was observed after ethylene glycol saturation which confirms again the absence of swelling clay.

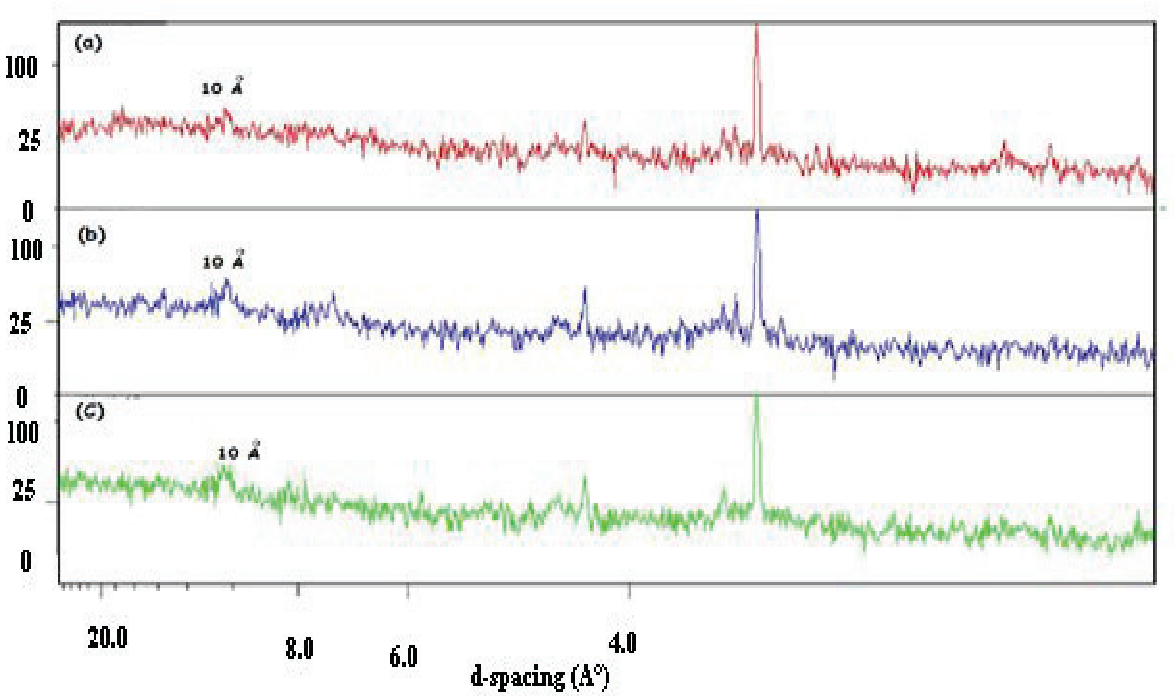


Fig.3. X-Ray diffraction of the (a) clay sample oriented,(b) clay calcinated at 500°C and (c) oriented lame saturated with ethylene glycol.

### 2.3. Cork

Cork coming from oak Maamora tree presented in figure 4 is a flexible material, light, compressible, resistant to gases and liquids, fire resistant and it acts as an outstanding acoustic and thermal insulator. Moreover, it's highly resistant to abrasion. Indeed all these characteristics are immensely influenced as a result of its chemical properties comprising of mainly suberin (45%) which can be echoed[14].

The density of used cork is 160 $Kg.m^{-3}$; the thermal conductivity is 0.049-0.05$W.m^{-1}.K^{-1}$.

Fig.4. View of Granular cork

## 3. Description of the experimental approach

### *3.1. Samples preparation and their corresponding measurement*

Samples object of work are presented in figure5.

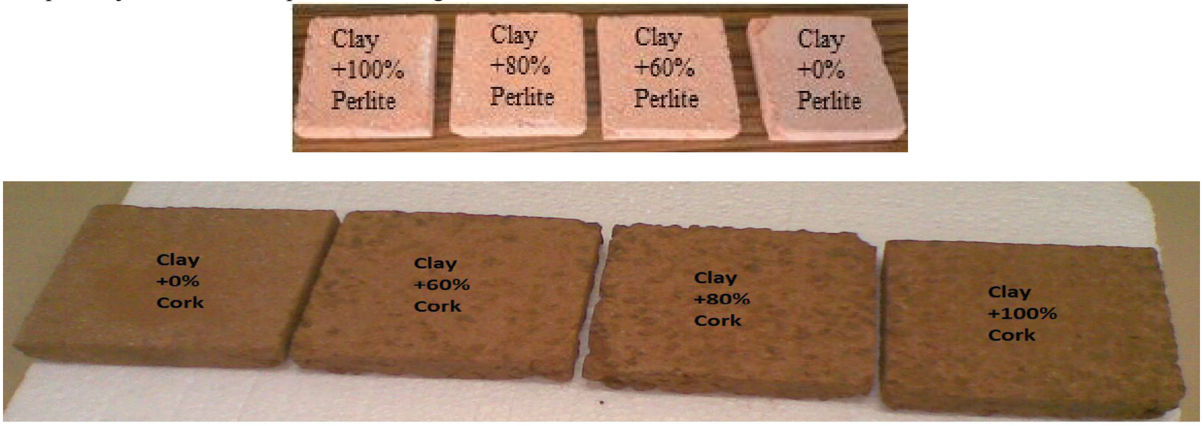


Fig.5. View of Illite Clay - Granular expanded perlite or granular cork in different volume fraction.

We prepared a number of four samples (clay/expanded perlite) corresponding to the four different percentage volume fraction of expanded perlite and four samples corresponding to four different percentage volume fraction of granular cork which size is ( d-D= 6.3-8mm). We used a normalized sieving process to take into account the effect of volume fraction of the insulating material on the thermal properties of the medium. Our experience has been done in a mold which dimensions are 100x100x20mm3, in this mold we filled a volume fraction of granular expanded perlite until we get a full mold, then we considered that this volume of granular corresponds to 100% in the samples and according to this we calculated the proportion corresponding to 80% as well as 60% of volume fraction granular expanded perlite or cork in the samples. Then we added clay in order to fill in the void existing between grains of insulating material. We also prepared samples of clay without granular, having the same dimensions as the other three, in order to compare the thermal properties variation of the mixture. The fours samples were dried in a stove, to remove moisture present into the pores of each one. In order to ensure that the samples are completely dried and no moisture in left in, the dried samples were weighted several times until we observed that the mass is becoming constant. The samples were then packed in plastic bags so they can maintain uniform moisture content near zero. Also Authors studied the effect of calcinations on thermal properties of the composite clay-expanded perlite by putting the samples on tunnel oven brand beralmar as indicated in figure 6.

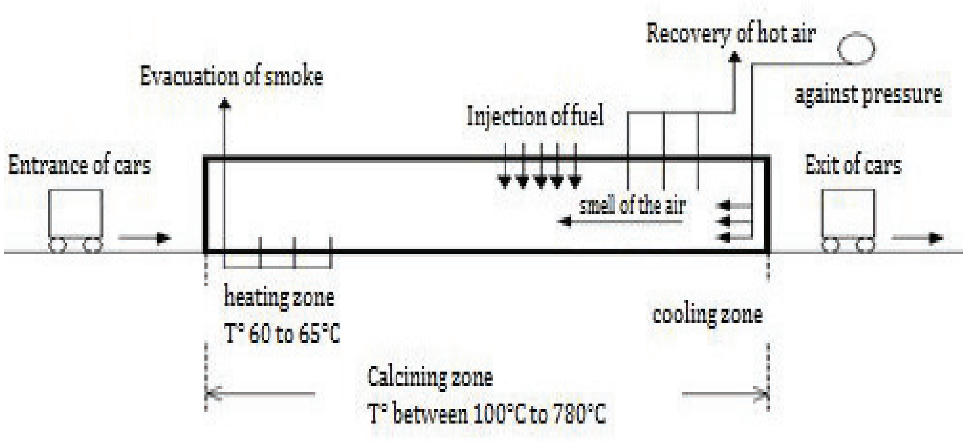


Fig.6. Schematics circuit calcination tunnel ovens

Knowing separately the densities of clay- insulating material and that of the mixture and depending on the mixture's law, we can deduce the granular insulating material volume fraction in each sample of the composite material according to the formula [2,5]

$$y = \frac{\rho_{c+ep} - \rho_c}{\rho_{ep} - \rho_c} \qquad (1) \qquad\qquad y = \frac{\rho_{c+co} - \rho_c}{\rho_{co} - \rho_c} \qquad (2)$$

## 4. Asymmetrical hot plate methods description

### *4.1. Transient Hot Plate method*

The thermal effusivity (E) and thermal capacity (ρc) were measured using the transient hot plate method[8-10]. Figure 7 illustrates the experimental device of this method

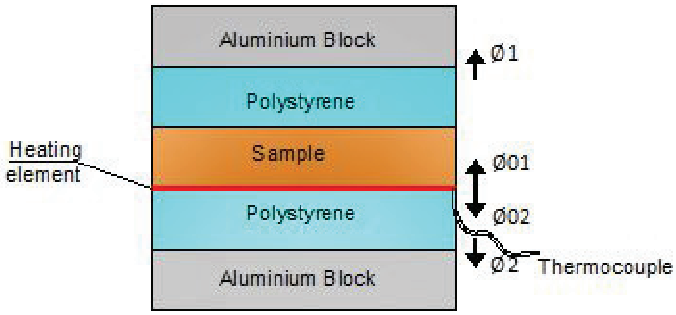


Fig.7. View and Schema of Asymmetrical Hot Plate device in transient regime.

### *4.2. Hot Plate in steady state regime*

The Hot Plate method in steady state regime [10–12] enables to characterize thermal conductivity (λ) of samples. Figure 8 illustrates the experimental device of this method, once the system reaches the steady state regime.

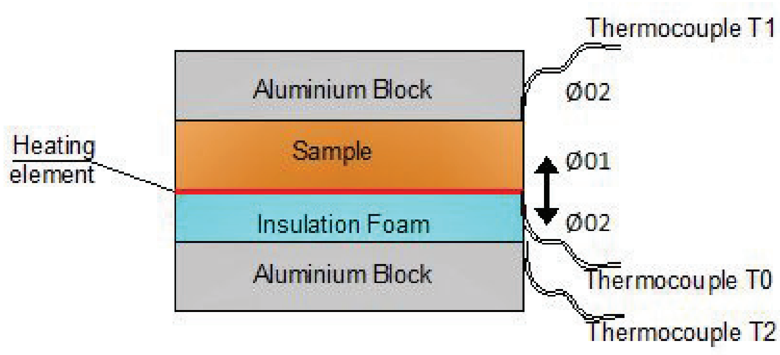


Fig.8. View and Schema of Asymmetrical Hot Plate device in steady state regime.

### *4.3. Experimental approach of the flash method*

This method permits to determine the diffusivity of solid [10–12] .Its principle is described in the fig.9.we send a strong luminary flow on the sample's parallel faces in a short period. A thermocouple in touch with the bottom face permits to register the rise of temperature in the moment when the face receives the flash. A modeling of heat transfer in the sample has been done to estimate the thermal diffusivity with the experimental thermogram.


Fig.9. Schema of flash method

## 5. Results

### *5.1. Density*

The densities measurements ρ of the all samples were made by weighing each sample and knowing their dimensions, the analysis of samples densities was done before and after calcination :Before calcination, the results indicate that for composite Illite clay-expanded perlite the density is decreasing from 2029 ($kg.m^{-3}$) (clay alone) to 1450 ($kg.m^{-3}$) (100%-expanded perlite) when the volume fraction expanded perlite is increasing.While after calcination, the density decreases from 1950(clay alone) to 1374 ($k.gm^{-3}$) (100%-expanded perlite) by the increase of volume fraction of expanded perlite. However, the results of Illite clay-cork indicate that the density is decreasing from 2029 ($kg.m^{-3}$) (clay alone) to 1109 ($kg.m^{-3}$) (composite clay-100%-cork).Figure 10 shows the results of the densities obtained according to volume fraction of granular: cork and expanded perlite (before and after calcinations). Authors conclude the observation below:

- ✓ The value of densities for the composite's Illite clay –granular cork is more interesting ( gain on lightness 45%) than Illite clay –expanded perlite, even after calcinations (gain on lightness 30% ) and this gain obtained is due to the creation of porosity inside the composites by adding cork or expanded perlite;
- ✓ The density of clay-expanded perlite doesn't vary a lot before and after calcinations and this small variation is due to the transformation of clay into terra cotta.
- ✓ Authors observe that there is a linear correlation between densities and volume fraction of materials insulting.

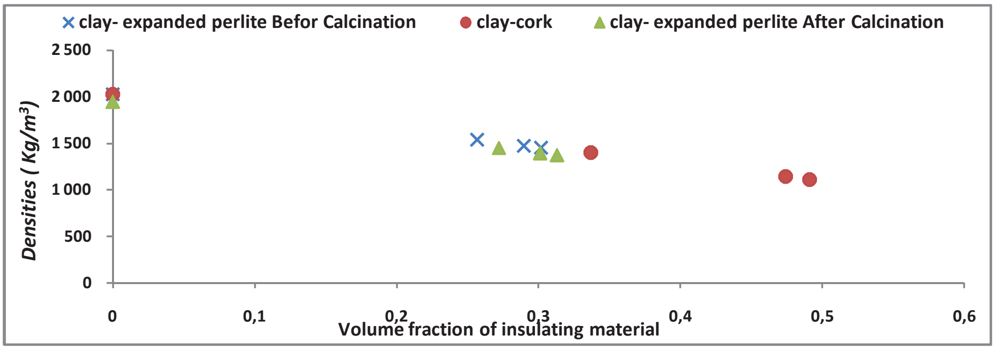


Fig.10. View of Densities according to different volume fraction of granular: cork and expanded perlite (before and after calcinations).

### *5.2. Thermal conductivity by the method hot plate in steady state regime*

The results for the analysis of thermal conductivity obtained by the hot plate method in steady state regime, concerning the composite clay-expanded perlite ,proves that when the volume fraction of expanded perlite is increasing before calcinations, this thermal property decreases from 0.51 to 0.380 ($W.m^{-1}.K^{-1}$) while this property after calcination decreases from 0.354 to 0.258($W.m^{-1}.K^{-1}$).However in comparison with Illite clay-cork, we observe that the thermal conductivity decreases from 0.51(clay alone) to 0.246 ($W.m^{-1}.K^{-1}$) (for composite clay-100% cork) when the densities is decreasing. Figure 11 shows the plot of the results of the thermal conductivities of the two composite according densities allows to conclude the observations below:

- ✓ We note that the thermal conductivities of the composite clay-expanded perlite air dried are far from the results obtained from the composite clay-cork.
- ✓ The granular cork with clay permits a significant decrease of thermal conductivity, while the granular expanded perlite permits a decrease of thermal conductivity lower than the one obtained by cork (gain of 30% using perlite instead of 52% for cork);
- ✓ The value of the thermal conductivity for the composite clay-cork air dried ,are above the same value as the composite clay-expanded perlite heated, so we conclude that the results of the composite clay-cork are more interesting than those of clay-expanded perlite in term of energy gain;
- ✓ The figure 11 shows thermal conductivity according to density and permit to authors to deduce a linear correlation between those parameters;
- ✓ The improvement of thermal conductivity after calcination is due to the higher firing temperatures which produces more vitrification phases inside the matrix clay-expanded perlite.

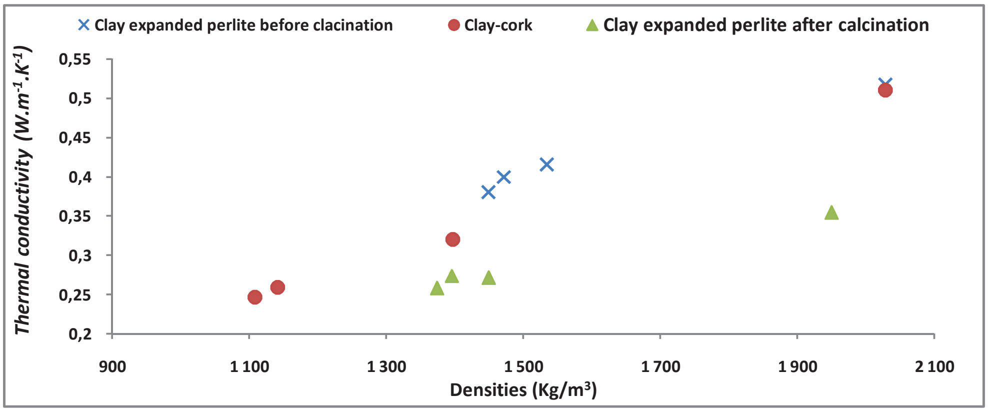


Fig .11.View of Thermal conductivity according to densities of composites Illite clay-granular cork and Illite clay-expanded perlite before and after calcinations.

### *5.3. Thermal Effusivity by the method hot plate in Transient regime*

The results of the thermal effusivity obtained by the hot plate method in transient regime for the composite Illite clay-expanded before calcinations indicate that this property is decreasing from 862 to 641 ($J.m^{-2}.K^{-1}.s^{-1/2}$) while this property after calcinations decreases from 740 to 489 ($J.m^{-2}.K^{-1}.s^{-1/2}$) when the volume fraction of expanded perlite is increasing. However, the thermal effusivity for Illite clay-granular cork decreases from 862 to 492 ($J.m^{-2}.K^{-1}.s^{-1/2}$) (for composite 100% cork) with the increase of granular cork volume fraction and the decrease of the density. Figure 12 shows the plot of the results of the thermal effusivity of the two composite according densities allows to conclude that:

- ✓ The values of thermal effusivities obtained from the composite clay-expanded perlite air dried, are so lower than the value of the composition clay-cork.
- ✓ Adding the granular cork on composite permits a gain of 43% on thermal effusivities while the expanded perlite permits a gain of 30%.
- ✓ The value of the thermal effusivities of the composite clay-cork air dried, are above the same value as the composite clay-expanded perlite heated, so we conclude that the results of the composite clay-cork are more interesting than those of clay-expanded perlite in term of energy gain.
- ✓ The decrease of the thermal effusivity of our composites conduct to conclude that the composite clay-expanded perlite after calcinations absorbs more heat flow than clay-granular cork.
- ✓ This significant decrease obtained from clay-expanded perlite is due to the heat spending by calcinations of the material. This decrease of thermal effusivity permits to limit the thermal exchange with the outside environment.
- ✓ The figure 12 shows thermal effusivity according to density and permits to authors to deduce a linear correlation between those parameters.

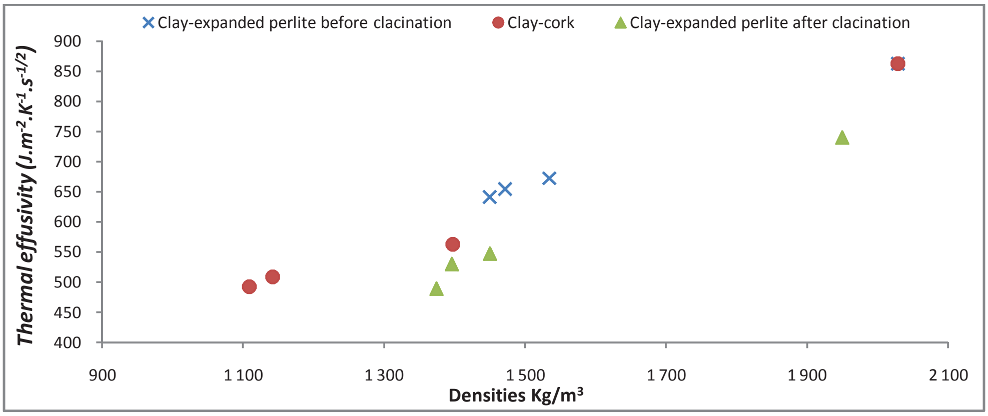


Fig12. View of Thermal Effusivity according to densities of composite Illite clay-granular cork and Illite clay-expanded perlite before and after calcination.

### *5.4. Thermal diffusivity by the flash method*

The results before calcinations indicate that the thermal diffusivity is decreasing from 5.06 to $3.71.10^{-7}$ ($m^2.s^{-1}$) while this property after calcinations decreases from 2.79 to $2.44x10^{-7}$ ($m^2.s^{-1}$) when the volume fraction of expanded perlite is increasing. While the thermal effusivity for the composite clay-cork decreases from $5.07.10^{-7}$ (clay alone) to 3.09 $.10^{-7}$($m^2.s^{-1}$) (clay-100% cork) when the volume fraction cork increases. Figure 13 shows the plot of the results of the thermal diffusivity of the two composite according densities allows to observe that:

- ✓ the thermal diffusivity is decreasing proportionally to the decrease of the densities of the composites;
- ✓ Adding the granular cork on composites permit a gain of 40% for the values of thermal diffusivity while the expanded perlite permits 30%;

- ✓ The thermal diffusivity results of the composite Illite clay –granular cork air dried are more interesting than Illite clay –expanded perlite heated. so the transfer of heat flow takes more time to cross the composite clay granular cork in comparison with clay expanded perlite;
- ✓ The value of the thermal diffusivity of composite Illite clay- granular cork air dried are so lower than those obtained by the combination of Illite clay –expanded perlite.

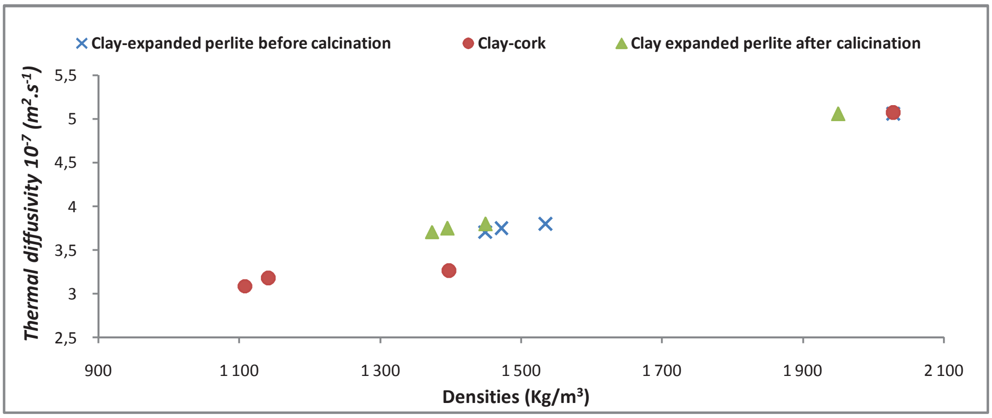


Fig.13. View of Thermal diffusivity according to densities of the different materials studied.

### 5.5. Thermal performance of Illite Clay- granular cork or expanded perlite compared with Illite clay alone

The Experimental investigation of the thermal properties of the composite material based on the ecological materials Illite clay -granular cork or expanded perlite was made for the purpose of its use as a walls or slab. The comparison of blocks with the same thickness done from materials: clay-cork, clay-expanded perlite and clay alone subject to the same difference of the temperature gives the relation cited below:

For an area of 1 m$^2$

$$\emptyset = \frac{\Delta T}{Rt} \quad (3) \qquad \emptyset = \frac{\Delta T}{R_t} \quad with\ R_t = \frac{1}{U} = \sum_i R_i \quad (4) \qquad [2,5]$$

The thermal resistance of conduction for a homogeneous wall

$$R = \frac{e}{\lambda} \quad (5) \qquad \emptyset = \frac{\Delta T.\lambda}{e} \quad (6)$$

So we can deduce for the same thickness and for an area of 1 m$^2$

$$\frac{\emptyset_{gr-clay}}{\emptyset_{clay}} = \frac{\lambda_{gr-clay}}{\lambda_{clay}} \quad (7)[2,5]$$

This allows calculating the energy saving by using this:

$$Energie\ saving = 100 \times \left(1 - \frac{\emptyset_{gr-clay}}{\emptyset_{clay}}\right) \quad [2,5]$$

We can deduce for the same thickness and for an area of 1m$^2$

$$\frac{\emptyset_{ep-clay\ after\ cacination}}{\emptyset_{ep-clay\ before\ calcination}} = \frac{\lambda_{ep-clay\ after\ cacination}}{\lambda_{ep-clay\ before\ calcination}} \quad (9)$$

[2,5]

This allows calculating the Dissipated energy by using this:

$$\boldsymbol{Dissipated\ energy} = \mathbf{100} \times \left(\frac{\phi_{ep-clay\ after\ cacination}}{\phi_{ep-clay\ \ before\ calcination}}\right) \qquad (\mathbf{10}) \qquad [2,5]$$

Table.1 shows the results of the Energy saving of the two composite and Dissipated Energy for the calcination . We note that the energy saving values obtained from the composite Illite clay- granular cork air dried are above two times more than the values obtained with composite Illite clay-expanded perlite without using the energy of heated .While those results comparing with those values with the composite Illite clay-expanded Perlite heated.

| | Illite clay-cork 100% | Illite clay-cork 80% | Illite clay-cork 60% |
|---|---|---|---|
| Energy saving (%) | 51,76 | 49,22 | 37,25 |
| Densities ratio | 0,55 | 0,56 | 0,69 |
| | Illite clay-expanded perlite 100% | Illite clay-expanded perlite 80% | Illite clay-expanded perlite 60% |
| Energy saving before calcination(%) | 26,50 | 22,63 | 19,73 |
| Dissipated energy for calcination (%) | 67,89 | 68,50 | 65,30 |
| Densities ratio before calcination | 0,71 | 0,73 | 0,76 |
| Densities ratio after calcination | 0,70 | 0,72 | 0,74 |

Table 1: Energy saving dissipated energy for calcinations and Densities ratio between Illite clay without insulating material and insulating material –Illite clay composite.

**Conclusion**

The purpose of this work is the thermal characterization of both composites: Illite clay-granular-cork and Illite clay-expanded perlite, to estimate the energy saved stemming from two composites and the energy dissipated in calcination of the composite Illite clay-expanded perlite, to show the role of the choice of granular in the improvement of the thermal properties while maintaining a comparison of result obtained for every composite. We conclude that the thermal properties of the composite Illite clay-granular cork are twice more superior to the thermal properties of the composite Illite clay- expanded perlite, even under the effect of calcinations. This observation permit to say that the results obtained from the composite Illite clay-expanded perlite are inconsiderable in comparison with the values of Illite clay-cork, without taken into account the energy dissipated in calcinations.

Authors recommend the choice of the composite Illite clay-cork for building construction in Bensmim area for its high thermal properties, its ecological quality in comparison with the composite Illite clay-expanded perlite, as well as its resistance to the hard climatic condition, its role in the preservation of the environment and it's low cost.

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